

Non-detection of pulsed radio emission from magnetar Swift J1834.9–0846: constraint on the fundamental plane of magnetar radio emissions

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Abstract The magnetar Swift J1834.9–0846 is observed using Nanshan 25 meter radio telescope. No pulsed radio emission is detected. The upper limit on pulsed radio emission from this source is 0.5 mJy. According to the “fundamental plane” of magnetar radio emissions, this source should have radio emissions. Therefore, our results put constraints on the existence of fundamental plane of magnetar radio emissions. It may be that a small quiescent X-ray luminosity is only a necessary condition for magnetar radio emissions.

Key words: pulsars individual:Swift J1834.9–0846—stars:magnetar—stars:neutron

1 INTRODUCTION

Magnetars are assumed to be magnetism-powered neutron stars. They form a different pulsar population from that of rotation-powered pulsars. Normal rotation-powered pulsars are usually radio emitters. They are commonly known as radio pulsars. However, magnetars manifest themselves mainly as anomalous X-ray pulsars (AXPs) and soft gamma-ray repeaters (SGRs). All of them are radio quiet until recently. The discovery of transient pulsed radio emissions from one magnetar has bridged the gap between radio pulsars and magnetars (Camilo et al. 2006). Up to now, more than twenty magnetars have been discovered¹. Three of them are radio-loud magnetars (Camilo et al. 2006; Camilo et al. 2007; Levin 2010).

Recently, Rea et al. (2012) try to understand magnetar radio emissions from an empirical point of view. They proposed that magnetars are radio-loud if and only if their quiescent X-ray luminosities are smaller than their rotational energy loss rate: $L_{\text{qui}} < \dot{E}$. This is the key point of the “fundamental plane” of magnetar radio emissions. Since Rea et al. (2012) published their paper, there are two new sources up to now: SGR Swift J1822.3–1606 and SGR Swift J1834.9–0846. For the young magnetar SGR Swift J1834.9–0846, the upper limit of its quiescent X-ray luminosity is lower than its rotational energy loss rate (Kargaltsev et al. 2012). This source should be another radio-loud magnetar if the fundamental plane of magnetar radio emission proposed by Rea et al. (2012) is correct.

1.1 X-ray observations of SGR Swift J1834.9–0846

According to Kargaltsev et al. (2012), SGR Swift J1834.9–0846 has a rotation period 2.48 sec and period derivative $\dot{P} = 0.796 \times 10^{-11} \text{ s s}^{-1}$. Its characteristic magnetic field is $B = 3.2 \times 10^{19} \sqrt{P\dot{P}} = 1.4 \times 10^{14} \text{ G}$. It may also in association with the supernova remnant W41 (Tian et al. 2007). Therefore, SGR Swift J1834.9–0846 is similar to the radio emitting magnetar AXP 1E 1547.0–5408 (Camilo et al.

¹ McGill online catalog: <http://www.physics.mcgill.ca/~pulsar/magnetar/main.html>

2007): similar rotation period, similar characteristic magnetic field, and both are young sources in association with supernova remnants. The rotational energy loss rate of SGR Swift J1834.9–0846 is $\dot{E} = 3.95 \times 10^{46} \dot{P} P^{-3} = 2.1 \times 10^{34} \text{ erg s}^{-1}$. According to figure 3 in Kargaltsev et al. (2012), Swift/XTR observed a declining flux of SGR Swift J1834.9–0846. Therefore, from figure 3 in Kargaltsev et al. (2012), the upper limit of the source’s quiescent flux is: $f_{\text{qui}} < 3 \times 10^{-12} \text{ ergs}^{-1}$. The corresponding upper limit of the source’s quiescent luminosity is $L_{\text{qui}} = 4\pi d^2 f_{\text{qui}} < 5.7 \times 10^{33} d_4^2 \text{ ergs}^{-1}$. Here the source distance is chosen as 4 kpc, considering its association with the supernova remnant W41 (Tian et al. 2007). Furthermore, pre-outburst XMM and Chandra observations show that the source flux is about 100 and 1000 times smaller, respectively (Section 3.3.2 in Younes et al. 2012; Section 6.2.3 in Kargaltsev et al. 2012). Therefore, the quiescent luminosity of SGR Swift J1834.9–0846 must be smaller than its rotational energy loss rate.

This source meets all the criteria of the fundamental plane of magnetar radio emissions.

1. Quiescent X-ray luminosity smaller than the rotational energy loss rate.
2. A high acceleration potential along pulsar open field line regions. For SGR Swift J1834.9–0846, the corresponding acceleration potential is: $\Delta V = 4.2 \times 10^{20} \sqrt{\dot{P}/P^3} = 3.0 \times 10^{14} \text{ Volts}$.
3. Burst/outburst to trigger the radio emissions. It shows SGR-type bursts on 2011 August 7. Its declining flux means that it has an outburst recently.
4. It lies relatively nearby. A possible distance of 4 kpc is obtained considering its association with supernova remnant W41.

If the fundamental plane proposed by Rea et al. (2012) is correct, SGR Swift J1834.9–0846 should have radio emissions. And from previous experience of magnetar radio emissions, we should detect its radio emissions in recent years. Therefore, SGR Swift J1834.9–0846 provides us the first opportunity to test the “fundamental plane” of magnetar radio emissions.

We observed SGR Swift J1834.9–0846 using Nanshan 25 meter radio telescope (Xinjiang Astronomical Observatory) on 24, June, 2012 for 1.0 hour. Data were taken with the cryogenic receiver at a center frequency of 1540 MHz. A bandwidth of 320 MHz was used in our observation, split into 128 contiguous 2.5 MHz frequency channels (Wang et al. 2001). Dual linear polarizations were summed, and the frequency channels were one-bit sampled every 1.0 ms. The data were recorded on computer disk and transferred from the observatory to a linux computing server for processing. No pulsed radio emission is detected². Our observations put constraints on the fundamental plane of magnetar radio emissions.

Section 2 is data analysis and results. Section 3 is discussions and conclusions.

2 DATA ANALYSIS AND RESULTS

The data were first checked for the exist of radio frequency interference (RFI) which has on dispersion. Interference signals above 5σ threshold level were excised from the raw data prior to our analysis.

2.1 Folding Search

The data were analysed using the pulsar signal processing package SIGPROC³ (Lorimer et al. 2000) on the computing server at Xinjiang Astronomical Observatory. The maximum DM detected in the known pulsars is 1456 pc cm^{-3} . According to the NE2001 Model for the Galactic Distribution of free electron (Cordes & Lazio 2001), SGR Swift 1834.9–0846 has a DM of 197 pc cm^{-3} assuming the distance of 4 kpc. So the data were de-dispersed using 750 trial DMs ranging from 0 to 1500 pc cm^{-3} . For each DM trial, the full 320 MHz of bandwidth was de-dispersed.

A bary-centric folding period was determined using measurement from previous X-ray observation of Swift J1834.9–0846. With the reported periods and their associated uncertainties from the *RXTE*

² We also observed this source for 1.0 hour in May 2012, which is also not detected.

³ See <http://sigproc.sourceforge.net>

observations, we extrapolated the period to the 2012 June epoch and determined the bary-centric folding period to be 2.48249785(10) s.

Periods ± 5 ms ($\sim 0.2\%$) from the nominal period were searched with a steps of 0.01 ms. Each of these folding trials was conducted for DMs between 0 and 1500 pc cm $^{-3}$ with steps 2 pc cm $^{-3}$. A total of 375,000 DM and period combinations were tried (750 DM trials, and 500 folds per DM trial), and for each trial the χ^2 significance of the folded profile was recorded. We would chose 5σ as a reasonable threshold for signal, and we found no proof for the folded profiles at the 5σ significance level or higher in the search.

2.2 Limits on Radio Emission

We can estimate the upper limit for pulsed radio flux which represent the minimum detectable flux density from a pulse period P by using equation (Manchester et al. 1996)

$$S_{\min} = \frac{\alpha \beta T_{\text{sys}}}{G \sqrt{N_p} \Delta t \Delta \nu} \sqrt{\frac{W_e}{P - W_e}} \quad (1)$$

Here α is the minimum S/N considered (in this case 5.0), β is a factor of ~ 1.5 accounting for the sensitivity reduction due to digitization and other losses, T_{sys} is the sum of the system noise temperature and the sky temperature in K, G is the gain of the radio telescope in K Jy $^{-1}$, Δt is the integration time in s, N_p is the number of polarizations and $\Delta \nu$ is the total bandwidth in Hz and W_e is the effective width of the pulse:

$$W_e = \sqrt{W^2 + \delta t^2 + \delta t_{\text{DM}}^2 + \delta t_{\text{scatt}}^2}. \quad (2)$$

Here it's value depends on the intrinsic pulse width W , the sampling time δt , the broadening of the pulse introduced by the dispersion of the signal in each 2.5-MHz channel δt_{DM} and the scattering broadening induced by inhomogeneities in the inter stellar media δt_{scatt} .

With the appropriate values for the observing system ($G = 0.1$ K Jy $^{-1}$, $T_{\text{sys}} = 40$ K, $N_p = 2$, $\Delta t = 3600$ s, $\Delta \nu = 320$ MHz.), and effective pulse width of 6 per cent of the pulse period, we obtain upper limits on radio emission of Swift 1834.9–0846 as 0.5 mJy.

3 DISCUSSIONS AND CONCLUSIONS

According to the fundamental plane of magnetar radio emissions (Rea et al. 2012), a magnetar will have radio emissions if and only if it quiescent X-ray luminosity is smaller than its rotational energy loss rate $L_{\text{qui}} < \dot{E}$. For SGR Swift J1834.9–0846, it meets all the criteria of the fundamental plane of magnetar radio emissions. If the fundamental plane of magnetar radio emissions is correct, then it should have radio emissions. However, we detect no pulsed radio emissions from this source. It may be that the fundamental plane is only a necessary condition. For sources with $L_{\text{qui}} < \dot{E}$, they may have radio emissions. At the same time, they can also not have radio emissions. In the Rea et al. (2012) paper, two of five sources with $L_{\text{qui}} < \dot{E}$ have no radio emissions. With the addition of SGR Swift J1834.9–0846, a total of six sources have $L_{\text{qui}} < \dot{E}$. Three of them have radio emissions (AXP XTE J1810–4197, AXP 1E 1547.0–5408, and PSR J1622–4950). While the other three are not detected in radio (PSR J1846–0258, SGR 1627–41, and SGR Swift J1834.9–0846). It is possible that all the three radio-quiet magnetars are actually radio emitting sources. Because of beaming, absorption due to environment, or large distances etc, we do not detect their radio emissions. It is also possible that they have no radio emissions at all.

The X-ray emissions of magnetars are magnetism-powered. It has nothing to do with the rotational energy loss rate. However, the fundamental plane of magnetar radio emissions links the magnetar quiescent X-ray luminosity with its rotational energy loss rate. Rea et al. (2012) did this since they believed that the radio emissions of magnetars are rotation-powered. However, the characteristics of magnetar

radio emissions are very different from that of radio pulsars (Mereghetti 2008): a variable flux and pulse profile, a flat spectra, and most importantly it is transient in nature. If the radio emissions of magnetars are rotation-powered, the same as that of radio pulsars, we should see similar radio emission properties in radio magnetars and radio pulsars. However, this is not what we have observed. Then it is reasonable to think that the magnetar radio emissions are from a different energy reservoir. In the case of magnetars, the natural energy budget is the magnetic energy. Therefore, the radio emissions of magnetars may be magnetism-powered instead of rotation-powered. The X-ray emissions of magnetars can vary significantly. Then it is not surprising that their radio emissions are also variable, since they are from the same energy reservoir.

For young magnetars, they can also rotate very fast (e.g. AXP 1E 1547.0–5408 has a period of 2.1 sec, Camilo et al. 2007). The rotational energy is also very significant. Therefore, we may also expect some rotation-powered activities in magnetars (Zhang 2003). For example, there may also exist rotation-powered radio emissions in magnetars. Therefore, there could be two types of radio emissions in magnetars: magnetism-powered radio emissions and rotation-powered radio emissions. At present, only transient pulsed radio emissions are observed in magnetars. They are more likely to be magnetism-powered. In the future, more radio-loud magnetars will be discovered (e.g. by FAST or SKA etc). Among them, we may also see persistent radio emissions in some magnetars, with properties similar to that of radio pulsars. Then these radio emissions may be rotation-powered.

At present, three of six sources with $L_{\text{qui}} < \dot{E}$ have radio emissions. One physical reason is that: low luminosity magnetar tends to have similar magnetospheric structure as that of radio pulsars (Section 4.2 in Tong et al. 2012). The coherent radio emission conditions are more likely to be fulfilled in low luminosity magnetars. Only a relative low X-ray luminosity is required. It has few relation with the magnitude of rotational energy loss rate. Therefore, the “fundamental plane” of magnetar radio emissions (if it exists⁴) should be: “low luminosity magnetars are more likely to have radio emissions”. Nothing further can be said. Since our telescope is relatively small (25 meters in diameter), only a crude upper limit is obtained. Continued monitoring at other radio telescopes are highly recommended.

ACKNOWLEDGMENTS

This work is supported by the National Natural Science Foundation of China (11103021, 11173041, 10903019, 11003034), National Basic Research Program of China (973 Program 2009CB824800, 2012CB821800), West Light Foundation of The Chinese Academy of Sciences (Grant No. XBBS200920, XBBS201021).

References

- Camilo, F., Ransom, S. M., Halpern, J. P., et al., 2006, *Nature*, 442, 892
- Camilo, F., Ransom, S. M., Halpern, J. P., et al., 2007, *ApJ*, 666, L93
- Cordes, J. M., & Lazio, T. J. W. 2002, arXiv:astro-ph/0207156
- Ho, W. C. G., 2012, arXiv:1208.1297
- Kargaltsev, O., Kouveliotou, C., Pavlov, G. G., et al., 2012, *ApJ*, 748, 26
- Levin, L., Bailes, M., Bates, S., et al., 2010, *ApJ*, 721, L33
- Lorimer, D. R., Kramer, M., Müller, P., et al. 2000, *A&A*, 358, 169
- Manchester, R. N., Lyne, A. G., D’Amico, N., et al., 1996, *MNRAS*, 279, 1235
- Mereghetti, S., 2008, *A&ARv*, 15, 225
- Rea, N., Pons, J. A., Torres, D. F., et al., 2012, *ApJ*, 748, L12
- Tian, W. W., Li, Z., Leahy, D. A., et al., 2007, *ApJ*, 657, L25
- Tong, H., Xu, R. X., Song, L. M., Qiao, G. J., 2012, arXiv:1205.1626
- Wang, N., Manchester, R. N., Zhang, J., et al. 2001, *MNRAS*, 328, 855

⁴ See also Ho (2012) for criticisms on the existence of fundamental plane of magnetar radio emissions.

Younes, G., Kouveliotou, C., Kargaltsev, O., et al., 2012, *ApJ*, 757, 39

Zhang, B. 2003, *Astrophysics and Space Science Library*, 298, 27 (astro-ph/0212016)